Hepatic outflow occlusion in laparoscopic hepatectomy

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Background

The application of laparoscopic techniques to major hepatic resection has been limited by the risk of hepatic vein laceration leading to massive bleeding or gas embolism. A balloon catheter has therefore been designed to occlude hepatic vein flow during experimental laparoscopic hepatectomy.

Methods

The procedure was attempted in 8 pigs weighing around 50 kg and submitted to laparoscopic left hemihepatectomy. A specially designed balloon catheter was inserted via the femoral vein and advanced into the retrohepatic segment of inferior vena cava (IVC). After inflation of the balloon with 17ml contrast, angiography confirmed complete occlusion of this segment, while a central rigid channel allowed passage of blood from IVC to right atrium. Haemodynamic studies were performed during resection of the left and left paramedial lobes of the liver, which was completed laparoscopically using ultrasonic coagulating shears and vascular linear staplers.

Results

Inflation of the balloon reduced mean arterial pressure to 75–79% and central venous pressure to 29–42% of baseline values, while cardiac output also fell (to 69–73% of basal). IVC blood flow decreased to 58% and hepatic venous flow to only 16% of pre-inflation values. Left hemihepatectomy was successfully achieved by the laparoscopic route in all 8 animals with a mean balloon inflation time of 30 min and blood loss of 166 ml. Haemodynamic indices returned to normal after deflation of the balloon at the end of the resection.

Discussion

This preliminary study shows that hepatic venous outflow can be occluded by this special balloon catheter and that animals can tolerate the associated haemodynamic disturbance. Similar techniques in man might permit major hepatectomy to be safely achieved by a laparoscopic approach.

Keywords

laparoscopic hepatectomy, experimental laparoscopic surgery, hepatic vein

Introduction

Laparoscopic surgery is now widely accepted, since it produces less trauma, rapid recovery and shortened hospital stay compared with conventional open operation. A wide variety of operations have been performed laparoscopically. However, laparoscopic liver surgery has developed slowly, with initial use restricted to diagnostic or other simple procedures such as laparoscopic-guided liver biopsies [1], liver cyst fenestration [2] and small hepatic wedge resections [3]. In recent years, there have been anecdotal reports of laparoscopic anatomical hepatectomy [4–5]. Hüscher [6] recently published his experience with laparoscopic-assisted hepatectomy, including right formal or extended right hepatectomy. These resections have been performed with a mini incision; an abdominal wall lift device and regular instruments were used to obviate the need for pneumoperitoneum. But to our knowledge, most clinical laparoscopic hepatic procedures have been limited to left partial or segmental hepatectomy. The aim of this study was to develop a new approach to occlude hepatic vein outflow by using a balloon catheter during laparoscopic hepatectomy. In this manner, the risk of intra-operative bleeding may be greatly reduced, and gas embolisation from inadvertent hepatic vein laceration could be prevented.

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Materials and methods

Animal preparation

Eight domestic pigs weighing 48–56 kg (average 51±2.8 kg) were submitted to laparoscopic left hemihepatectomy with balloon-catheter occlusion of the hepatic venous blood flow. The study was approved by the Institutional Animal Care and Use Committee. The animals were fasted except for water for 12 hours before operation. On the day of operation, they were premedicated with intramuscular atropine (0.04 mg/kg) and ketamine (20 mg/kg). Animals were placed in a supine position, and Pentobarbital (20 mg/kg) was administered for induction of anaesthesia after an intravenous line was started. The pigs were intubated with an endotracheal tube and receive Isoflurane (2%) for maintenance of anaesthesia. Blood samples for blood count and biochemical analysis were drawn pre- and postoperatively. The right femoral vein was dissected for catheterisation with the balloon catheter. An arterial line was inserted in the right femoral artery for continuous arterial pressure monitoring. A Swan-Ganz catheter (7.5 Fr; Baxter International, Irvine, CA, USA) was inserted into the right jugular vein, advanced into the pulmonary artery via pressure-wave guidance and connected to a pressure transducer and a monitor (Hewlett Packard, Boeblingen, Germany). Electrocardiogram leads were placed and connected to the same monitor. Haemodynamic studies were performed to assess the effects of balloon inflation preoperatively. The heart rate, blood pressure, operative blood loss, volume of infused fluids and operative time were recorded intra-operatively.

Catheter design and catheterisation

A balloon catheter (Numed Inc., Hopkinton, NY, USA) was specially designed for this study (Figure 1). The length of the catheter is 120 cm and that of the balloon is 6 cm, with a diameter of 20 mm when inflated; the volume of the balloon is 17 ml. An 11-cm rigid tube with a diameter of 3 mm for blood shunt lies in the centre of the balloon. The catheter, with the balloon immersed in 80 ml heparin solution (100 U/ml), was inserted into the femoral vein and advanced into the retrohepatic IVC under fluoroscopic guidance. The balloon of the catheter was inflated with 17 ml contrast, which was positioned to ensure complete hepatic vein occlusion (Figure 2). An angiography catheter was then inserted through the left femoral vein, and contrast was injected into the inferior vena cava (IVC). Angiography confirmed complete occlusion of the retrohepatic IVC and demonstrated blood flow through the central lumen of the balloon from IVC to right atrium (Figure 3).

Haemodynamic studies

The basal values of cardiac output (CO), mean arterial pressure (MAP), central venous pressure (CVP) and heart rate (HR) were obtained. Pneumoperitoneum was established through a Veress' needle to 15 mmHg, and another set of haemodynamic measurements was obtained. The balloon of the catheter was next inflated with 17 ml air, and haemodynamic parameters obtained after 10, 20 and

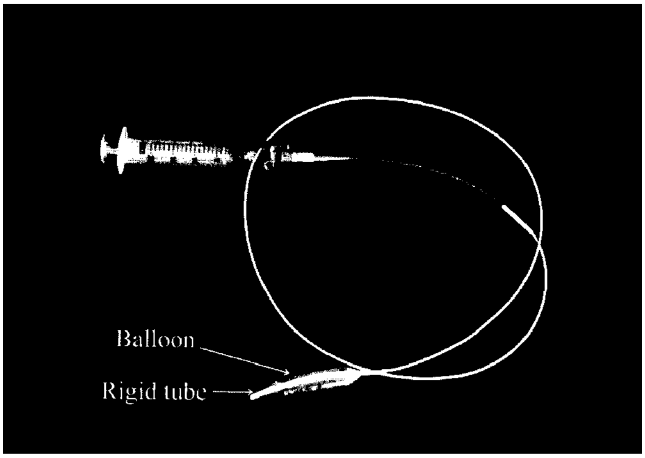

Figure 1. *The specially made balloon catheter with a rigid tube in the centre of the balloon for blood shunt.*

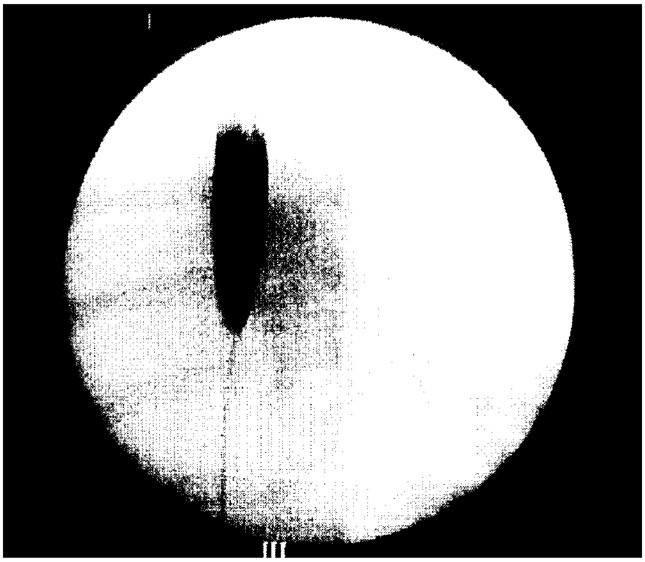

Figure 2. *The balloon of the catheter was placed in the retrohepatic inferior vena cava which was inflated with 17 ml of contrast. The position of the balloon was confirmed under fluoroscopy.*

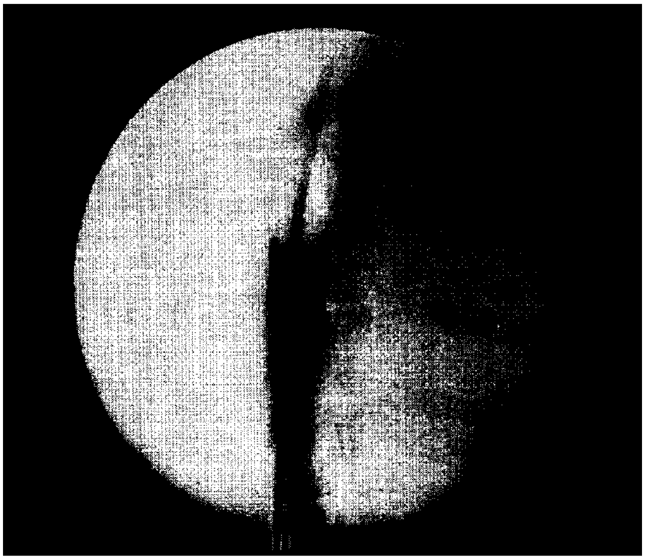

Figure 3. *Angiography confirmed complete occlusion of the retrohepatic IVC and demonstrated blood flow through the central lumen of the balloon from IVC to right atrium.*

30 min of balloon inflation. The balloon was then deflated and haemodynamic measurements were repeated 10, 20 and 30 lara.

IVC and hepatic venous flow measurement

The pigs were placed in the supine position. A 10 mm trocar was introduced via an infraumbilical incision through which a 30° laparoscope was inserted. Four 12-mm trocars were inserted through the anterior abdominal wall under direct vision in the following locations: two in the right and left upper quadrants along the anterior axillary line and two in the right and left midclavicular lines between the umbilicus and the upper quadrant trocars. To measure the effects of the balloon inflation on IVC and hepatic venous blood flow, a 7.5-MHz laparoscopic Doppler ultrasound probe (B&K Medical, Copenhagen, Denmark) was inserted through the left upper quadrant port and was placed directly on the surface of the IVC. Basal blood flow velocity and diameter of the IVC were obtained in a transverse section. Keeping the probe relatively fixed, the measurements were repeated following complete balloon inflation and then deflation. The probe was moved to the left paramedial lobe, a hepatic vein was detected, and the diameter and flow (BF) velocity of the vein were measured under conditions of basal pneumoperitoneum, balloon inflation and deflation. The blood flow in the IVC and hepatic veins was calculated as follows: BF=mean velocity$\times\pi\times$(diameter/2)^2.

Operative technique

A left hemihepatectomy (left and left paramedial lobes) was performed in this experiment. A planned resection line on the surface of the liver was scored with a monopolar electrocautery scissor. The lobe to be resected was retracted with an atraumatic clamp by an assistant. An ultrasonic coagulating shears (US Surgical Co., Norwalk, CT, USA) was used to dissect hepatic parenchyma and small vessels of the liver. Endo GIA II 45 mm vascular linear staplers (US Surgical Co., Norwalk, CT, USA) were used to dissect larger vessels or ducts. Haemostasis of the cut liver edge was achieved by monopolar-electric or ultrashear cautery. The balloon of the IVC catheter was inflated when the hepatic veins were approached and then deflated after ensuring careful haemostasis of the cut liver edge. Irrigation and aspiration during the dissection were performed continuously to maintain a clear operative field. The specimen was placed into an entrapment bag (US Surgical Co., Norwalk, CT, USA) and brought out of the abdomen through an extended port incision. The operative field was irrigated and suctioned. The pigs were sacrificed and a midline abdominal incision was made. The cut edge of the liver was inspected, and hepatic and kidney biopsies were performed.

Data analysis

The data were presented as mean±standard deviation. Statistical comparisons among the groups with respect to continuous variables were analysed using paired analysis of variance. Blood count and chemistries were analysed by using Student's t test. Statistical significance was defined as $p<0.05$.

Results

Haemodynamic studies

MAP decreased to 75–79% of its initial value at 10, 20 and 30 min after balloon inflation ($p<0.01$) and returned to baseline immediately after deflation (Figure 4). CVP decreased significantly after balloon inflation. The mean values decreased to 42, 33 and 29% of basal values at 10, 20 and 30 min after balloon inflation respectively. Obvious elevation of CVP was observed after balloon deflation (Figure 5). Cardiac output decreased to 69–73% of initial values after balloon inflation and returned to normal immediately after balloon deflation (Figure 6).

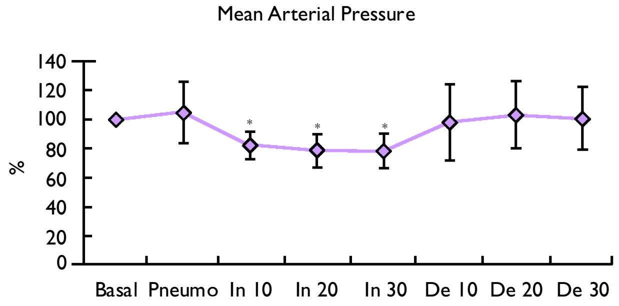

Figure 4. *Effects of balloon inflation on MAP level. Results are expressed as percentage of basal value. *p<0.00 l vs basal value. Pneumo: set-up pneumoperitoneum. In 10–30: 10, 20, 30 min after inflation of the balloon. De 10–30: 10, 20, 30 min after deflation of the balloon.*

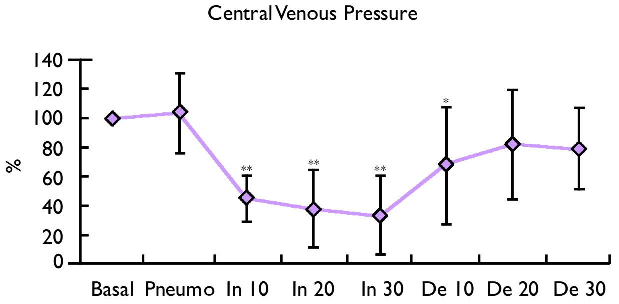

Figure 5. *Effects of balloon inflation on CVP values. Results are expressed as percentage of basal value. *p<0.05, **p<0.01 vs basal value. Pneumo: set-up pneumoperitoneum In 10–30: 10, 20, 30 min after inflation of the balloon. De 10–30: 10, 20, 30 min after deflation of the balloon.*

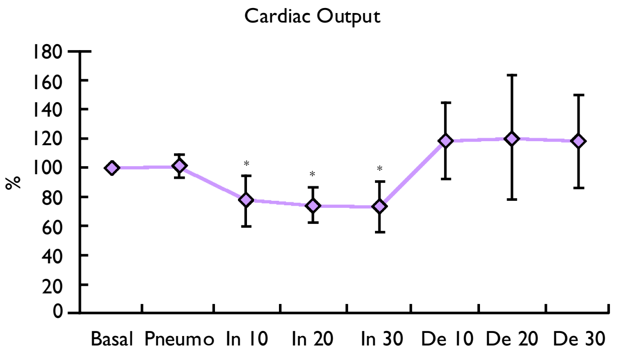

Figure 6. *Effects of balloon inflation on cardiac output. Results are expressed as percentage of basal value. *p<0.01 vs basal value. Pneumo: set-up pneumoperitoneum. In 10–30: 10, 20, 30 min after inflation of the balloon. De 10–30: 10, 20, 30 min after deflation of the balloon.*

Changes in IVC and hepatic venous blood flow

IVC blood flow decreased after balloon inflation to 58% of baseline values ($p=0.082$), returning to normal immediately after balloon deflation. The hepatic venous flow virtually disappeared after balloon inflation, decreasing to only 16% of baseline ($p=0.000098$). It returned to normal after balloon deflation (Table 1, Figure 7).

Table 1. *Effect of balloon inflation on IVC and HV blood flow*

	Basal	Inflation	Deflation
IVC	4.72 (1.96)	2.74 (0.97)	4.24 (2.57)
HV	0.58 (0.54)	0.09 (0.08)	0.57 (0.28)

IVC: inferior vena cava; HV: hepatic vein.
Values are mean (s.d.); *$p<0.01$ vs basal values

Laparoscopic hepatectomy

Eight consecutive pigs underwent successful left hemihepatectomy. Average operating time was 93$\pm$32 min (range, 55–140 min). The balloon inflation time was 30$\pm$8 min (range, 25–40 min), and mean blood loss was 166$\pm$88 ml (range, 50–270 ml). Blood count values did not change significantly. Levels of aspartate aminotransferase, total bilirubin and blood urea nitrogen increased significantly after operation. All animals underwent successful left hemihepatectomy without any damage to other organs or major vessels. No bleeding occurred from the cut edge of the liver after the operations were completed. Intraoperative MAP and electrocardiograms remained stable except during the period of balloon inflation, and returned to normal after balloon deflation.

Discussion

Laparoscopic techniques have been applied to a wide variety of hepatic operations. Some centres have performed laparoscopic liver biopsy, liver cyst fenestration and small wedge liver resection [1–3]. Laparoscopic hepatic surgery has evolved from simple to more complex procedures: from needle biopsy and wedge resection to partial nonanatomic hepatectomy and then anatomic lateral segmentectomy [3–8]. Most surgeons have been hesitant to apply this new technology to larger hepatic resections for fear of dangerous intraoperative bleeding or gas embolisation caused by hepatic vein laceration. Some authors have tried to occlude the IVC [9], hepatic veins [10] or portal vein by balloon catheter to reduce bleeding in open hepatectomy [11–12]. The Pringle manoeurve (occlusion of porta hepatis blood supply), used for a long time to prevent bleeding in open liver lobectomy, has also been utilised in laparoscopic hepatectomy [8,14]. But the most dangerous bleeding comes from lacerating the hepatic veins [8,13], when carbon dioxide insufflated at high pressure can enter into the vena cava through the open vessels to cause gas embolisation.

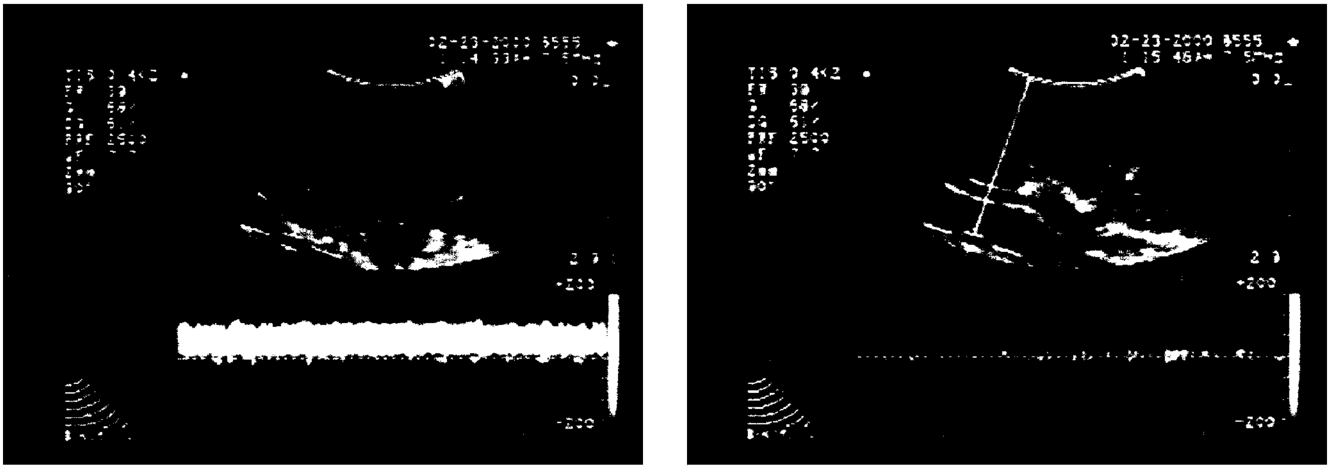

Figure 7a. *Measurements of hepatic venous blood flow by laparoscopic Doppler ultrasound. (a) Normal blood flow signal; (b) hepatic venous flow signal almost disappeared after balloon inflation.*

There are no descriptions in the literature describing hepatic outflow occlusion to prevent hepatic vein bleeding during laparoscopic hepatic resections. Our preliminary data show that hepatic outflow from hepatic veins can be effectively occluded with a specially made balloon catheter. Partial blood flow can pass from the IVC to the right atrium through the central shunt lumen in the catheter. The animals tolerated the haemodynamic disturbance caused by 30 min of balloon inflation and recovered after balloon deflation. Postoperative increase of serum hepatic enzymes and BUN in this experiment should be considered as the body response to hepatectomy and operative trauma. Therefore, it appears possible to reduce intra-operative bleeding and prevent gas embolisation from hepatic vein laceration during laparoscopic hepatectomy by using the technique described above.

In 1998, Wu and colleagues [13] described their experimental porcine model of laparoscopic left lateral hepatectomy. Mean intra-operative blood loss was 189±52 ml (range, 30–400 ml). In our study of left hemihepatectomy, mean blood loss was 166.25±88.95 ml (average, 50–270 ml), which seems a little less than Wu's report. Furthermore, we did not use the Pringle manoeuvre during the procedure. We attribute the low blood loss to the effect of hepatic vein occlusion by the balloon catheter. Angiography demonstrated blood flow through the central lumen of the balloon to the right atrium, and Doppler ultrasound revealed the near total elimination of hepatic venous blood flow during balloon inflation. These observations provide direct evidence that the balloon can effectively occlude hepatic venous outflow while permitting partial flow from the IVC to the right atrium. Testas *et al.* [15] described his experience using a Silastic balloon catheter with side-hole shunts during open hepatectomy. After 2 min of balloon inflation, the arterial blood pressure decreased to approximately 50% of its initial value and right atrial output declined by 30%. Our findings, however, indicate that MAP decreases to 75–79% and CO to 69–73% of the initial values, these reductions being less severe than those achieved by Testas.

Admittedly, anatomical differences between pig and man must be considered. The left lobes of a porcine liver are much thinner than those of a human. There are four lobes in a porcine liver: right, right paramedial, left paramedial and left. The vena cava is attached to the right lobe. Since it is nearly impossible to do a formal right lobectomy in a porcine model, we carried out a left hemihepatectomy in this study. It is much easier to do a left hemihepatectomy by using ultrasonic shears and Endo-GIA staplers in a porcine model. Significant differences in blood loss compared with a control group would have been difficult to prove without a large sample size. The effectiveness and safety of the balloon catheter in this experiment have been demonstrated by vena cava angiography and haemodynamic studies, and they compare well with existing literature on porcine hepatectomy. We therefore believe that our results support the idea that, with the combined use of a balloon occlusion catheter, electrocautery and/or ultrasonic coagulating shear, and Endo-GIA staplers, it should be possible to maintain adequate haemostasis and prevent gas embolisation during laparoscopic hepatectomy in man.

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